Sustainability with a focus on comparative LCA of retaining walls in South Africa

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Abstract

The use of geosynthetics has been developing rapidly in stature within the civil engineering and construction industries. This is largely due to its efficacy and cost-effectiveness. Concurrently, the need for sustainable engineering has become a necessity, which is essentially a supplementary advantage of using Geosynthetics in the built environment. There is a prominent advantage in using geosynthetics in relation to retaining walls and specifically Mechanically Stabilized Earth (MSE) walls over traditional solutions. There is further validity in using geosynthetics when an accurate Life-Cycle Assessment (LCA) is conducted. The LCA calculates and evaluates environmental factors and the potential impacts of the life cycle of a product, material, or service ((DEAT, 2004). This paper aims to present a comparison between traditional and sustainable engineering solutions with a specific emphasis on the retaining system that was considered in the recently constructed "Main Road – P728 project" by the Department of Transport, located in KwaZulu Natal. The cases of comparative LCA considered in this study are the Reinforced Concrete wall – RCC (Case A), MacRes MSE wall (Case B), and Paramesh MSE Wall (Case C).

Keywords: *Geosynthetics, Life-Cycle Assessment, Sustainable, Engineering, Environment*

1 Introduction

There are often operational constraints when constructing retaining systems in relatively remote locations, due to the availability of material, logistics, and cost implications. These are associated with traditional engineering solutions that have been implemented for many years. However, as the global ecological footprint of humans has increased by almost 80% since 1960 (Sharma, 2017), there has been a concentrated effort to measure and improve environmental management strategies. Accordingly, the construction industry has been driven to raise environmental awareness and assess their activity's impact on the environment. As a result, life cycle assessment (LCA) has emerged as a prominent tool to assess the environmental impact of products, materials, and services during a construction project (Selih & Sousa, 2006). The Life Cycle Assessment is an internationally accepted tool, and a global framework has been developed (ISO 14040:2006 and ISO 14044:2006), where it describes the principles and guidelines for LCA (Dossche, et al., 2017).

To thoroughly compare retaining systems and the environmental impacts stemming from traditional and sustainable engineering solutions, this paper details the results of the LCA that was performed for the recently completed project – Main Road P728, situated in KwaZulu Natal. There are three cases included in this comparison which are; Cantilever Concrete Wall (Case A), MSE Wall using MacRes (Case B) and MSE Wall using Paramesh (Case C). A design analysis of the three cases was completed, to ensure integrity of the data being presented and used in the calculation of the LCA.

2 Project Background

The upgrade of Main road P728 (km17+400 to km19+400) is a provincial road that is located in Umgababa (South of Durban, KwaZulu Natal) and transverses in a general Westerly direction. This project included a complete upgrade of the road. The existing topography exhibited various defects including scouring erosion concerns and loose gravel which made traveling unsafe. The proposed new upgrade deviated from the existing route and after assessment of the horizontal and vertical alignments, it was deemed compulsory to include retaining walls at necessary points to support the new carriageway.

During the evaluation process for the first retaining wall which was 81m long, the initial design consisted of a cantilever concrete retaining wall for lateral support of the carriageway. The MSE wall was proposed as an alternative with several benefits and savings to the client. The MSE wall using a concrete facing and the MSE wall using a Paramesh facing was considered. The Paramesh facing was eventually selected due to the intensive labor component that leads to job creation, the availability of local fill, and the cost benefits. Subsequently, the sustainability of the solution was an important factor in determining the final solution. A comparative Life Cycle Assessment of the three propositions was required. To determine the environmental benefits of the solution.

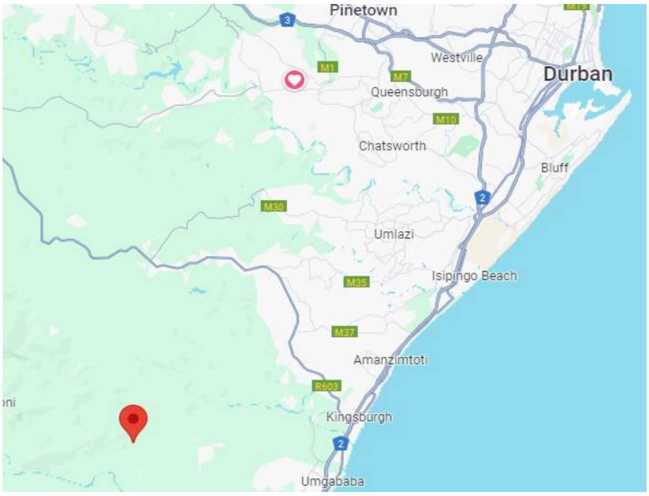

Figure 1: Locality of Main Road P728

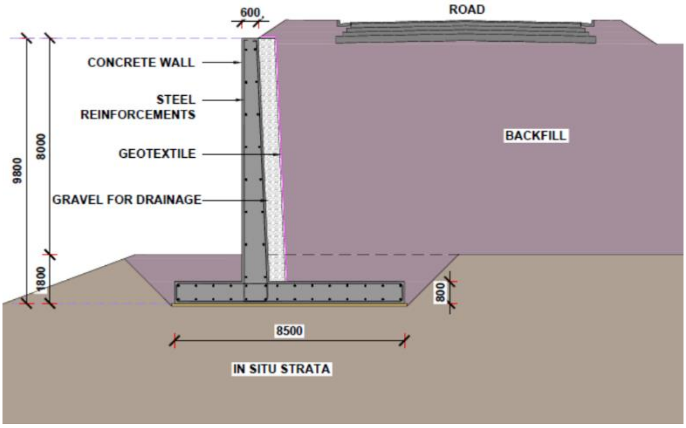

Figure 2: Case A: Reinforced Concrete Wall (RCC)

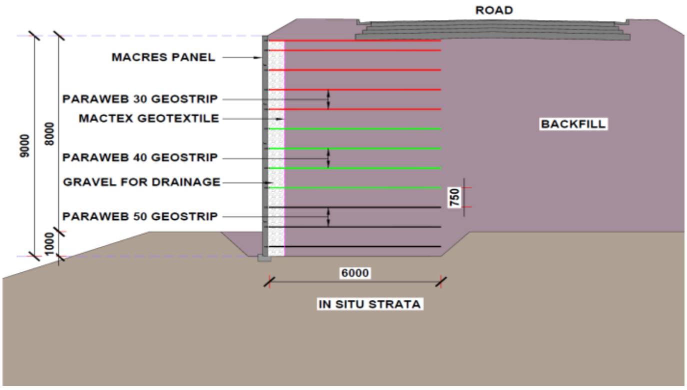

Figure 3: Case B: MSE Wall With Concrete Facia

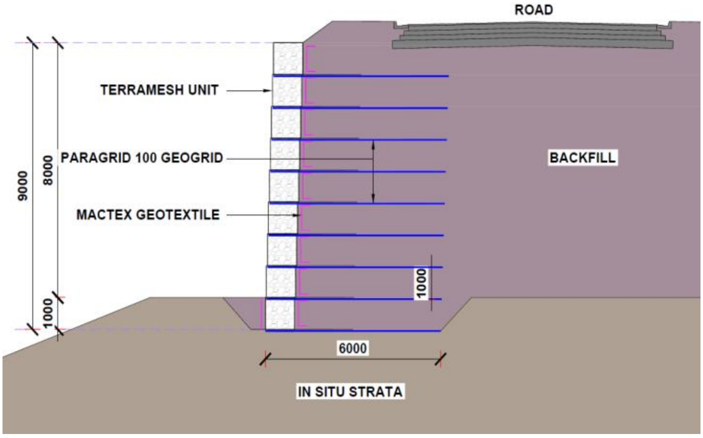

Figure 4: Case C: MSE Wall With Gabion Facia

3 Traditional Engineering Design Comparison

The Paramesh System consisted of a 1m x 1m wide and deep gabion, filled with gabion stone, with a secondary reinforcement tail premanufactured with the unit. The use of a 100 kN/m Geogrid (Paragrid 100) was laid every 1m lift to reinforce the structural soil that was used behind the wall. Due to the design methodology, 6m was the required length of geogrid to ensure the stability of the solution.

The MacRes System consisted of 140mm thick precast concrete panels which were reinforced with high adherence linear geostrips (Paraweb). The length of geostrips required was 6m to achieve global and internal stability.

The concrete wall is constructed by monolithically casting the stem and the base of the wall. The concrete retaining wall was dependent on bearing capacity from limiting settlement criteria as it is a rigid retaining wall. It was necessary to excavate to a depth of 1.8m to achieve acceptable results.

4 Sustainable Engineering Comparison

A comparative LCA was performed for cases A, B, and C as depicted in figure 2,3 and 4. The LCA was conducted on the average above-ground-level height of 8m which requires a total mechanical height of 9.8m (Case A), 9m (for Cases B and C) following traditional design methodologies. The critical component in the LCA study was the length of the wall of 81m. The system boundary selected for the assessment is “cradle to construction” in which maintenance, operation, and disposal after design life are not included in the assessment. SimaPro software was used in the LCA study, adopting CML-IA baseline V3.05 method. The relative distance for sea and road freight for the import of Geosynthetics from the manufacturing plant based in the United Kingdom (UK), has been considered for Cases B and C.

The following impact category indicators were considered in the assessment of environmental performance.

4.1 *Abiotic Depletion - Minerals & Fossil Fuel*
This impact category indicator is related to extraction of minerals and fossil fuels for any activity, thereby leading to its depletion. It is expressed as ‘kg Sb’ equivalents of minerals or in MJ equivalents of fossil fuels, due to the extraction activity. The geographic scope of this indicator is on a global scale.

4.2 *Global Warming Potential*
Climate change is related to emissions of greenhouse gases into the air. All substances which contribute to climate change are included in the global warming potential (GWP) indicator. The potential impact of the emission of one kilogram of greenhouse gas is compared to the potential impact of the emission of one kilogram CO2. The geographic scope of this indicator is on a global scale. The time span is typically 100 years.

4.3 *Ozone Layer Depletion*
Depletion of stratospheric ozone layer is caused by different gases. Due to this, a larger fraction of UV-B radiation reaches the earth surface, that will have harmful effects on human health, ani-mal health, ecosystems (terrestrial and aquatic) etc. The ozone depletion potential of

different gases is expressed as kg CFC-11 equivalent emissions. The geographic scope of this indicator is on a global scale. The time span is infinite.

4.4 *Photochemical Oxidation*
Photo-oxidant formation is the photochemical creation of reactive substances (mainly ozone), which affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides and volatile organic compounds in the presence of sunlight. PCO is expressed as kg Ethane equivalents per kg emission.

4.5 *Acidification Potential*
Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems etc. AP is expressed as kg SO2 equivalents per kg emission. The time span is eternity, and the geographical scale varies between local scale and continental scale.

4.6 *Eutrophication Potential*
Eutrophication includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water, and soil. NP is expressed as kg PO4 equivalents per kg emission. Time span is eternity, and the geographical scale varies between local and continental scales.

5 Results and Discussion

Table 1 below displays the input data that was considered for the comparative study. The data is based on the applicable design specific to the site requirement. The variation in material used, logistics, and energy consumption required for the each Case has been considered for the comparative study.

Table 1. Inputs for comparative Life Cycle Assessment of Cases A, B & C.

Item Description	Unit	Case A*	Case B**	Case C***
Wall height	m	9.8	9.0	9.0
Wall length (functional unit)	m	81.0	81.0	81.0
Excavation below ground level	m3	1,628	623	623
Boulders (inside gabion fascia)	ton	-	-	1,239
Lean mix concrete	m3	70	6.5	-
Structural concrete (M35 grade)	m3	1,134	102	-
Structural steel	kg	194,373	1,215	-
Bituminous insulation coating	kg	78	-	-
Laminated wooden formwork	m3	101	-	-
Gravel drainage layer	ton	394	394	-
Geo strip/grid soil reinforcement	m/m2	-	15,552	4,374
Geotextile for separation & filtration	kg	210	268	233
Paramesh MSE wall fascia units	kg	-	-	8,991
Diesel used in construction machineries	MJ	24,267	176,659	207,834

Table 2. LCA results in tabular format (CML-IA baseline V3.05 method)

Environmental Impact category	Unit	Case A*	Case B**	Case C***
Abiotic depletion - Minerals	kgSbeq	2.73E+00	4.16E-01	1.42E-01
Abiotic depletion - Fossil Fuels	MJ	8.03E+06	1.38E+06	7.08E+05
Global warming Potential (100a)	kgCO2eq	1.17E+06	3.66E+05	7.65E+04
Ozone Layer Depletion	kgCFC-11eq	6.23E-02	1.03E-02	8.22E-03
Petrochemical Oxidation Potential	kgC2H4eq	2.92E+02	2.66E+01	2.40E+01
Acidification Potential	kgSO2eq	3.47E+03	6.66E+02	2.26E+02
Eutrophication Potential	kgPO4eq	1.46E+03	2.38E+02	1.41E+02

**Case A: RCC wall, **Case B: MacRES MSE wall, ***Case C: Paramesh MSE wall*

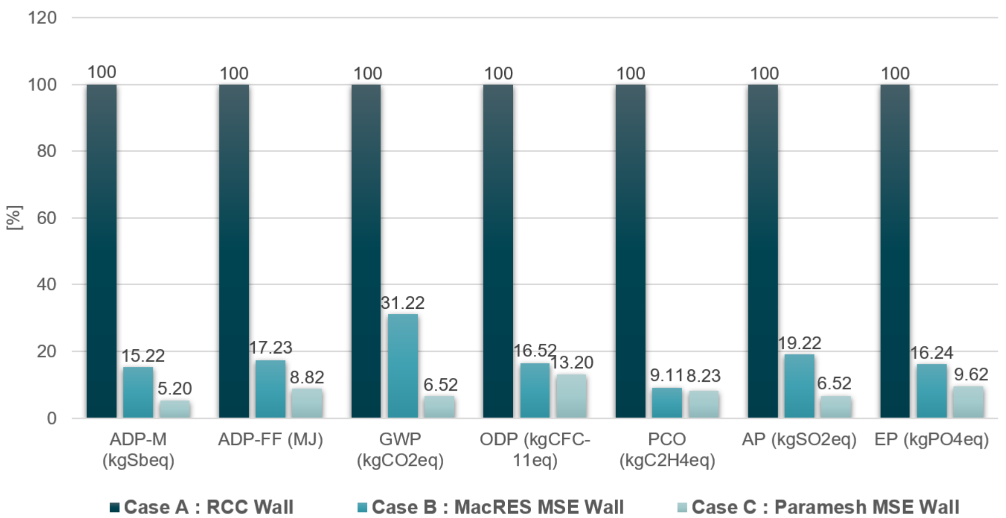

Figure 5: LCA results in chart format for characterization case (CML-IA baseline V3.05 method)

The environmental impacts of CASE B are reduced between 70% - 84% across all category indicators as opposed to case A, while a reduction of between 87% - 95% when considering the Paramesh MSE Wall (Case C).

Although it reasonably impacts the abiotic depletion of fossil fuels, due to energy and emissions during manufacturing and logistics, the use of Geosynthetics significantly contributes to the overall reduction in environmental impacts.

6 Cost Comparison

A comparative cost analysis was provided by a prominent retaining wall contractor in KwaZulu Natal (Obeca Civils). The cost provided included the price of material, transport to the site, plant required, and installation of each case. The following results were indicated.

Figure 6: Installed Cost Comparison

Considering the MSE Wall (Paramesh) as the base solution, the concrete wall proved to be 68% more expensive while the MSE Wall (Macres) was 26% more expensive than the MSE wall (Paramesh).

7 Conclusion

The ever-changing landscape of global industries has compelled businesses to develop new strategies to maintain sustainable businesses (Obonyo, 2020). The future direction of the industry is to promote additional sustainable solutions that describe solutions that exhibit less greenhouse gas emissions during manufacturing and construction, reduce exploitation of natural resources, and reduce energy consumption (Ferro & Vocciante, 2021).

The environmental impacts in construction are important to consider when assessing the sustainability of a project. This study shows that apart from the significant cost savings in using sustainable engineering solutions over traditional methods, there are also vast sustainability benefits from using geosynthetic systems in the built environment.

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